Instrument Incubator Program

INFLAME

In-situ Net FLux witin the AtMosphere of the Earth

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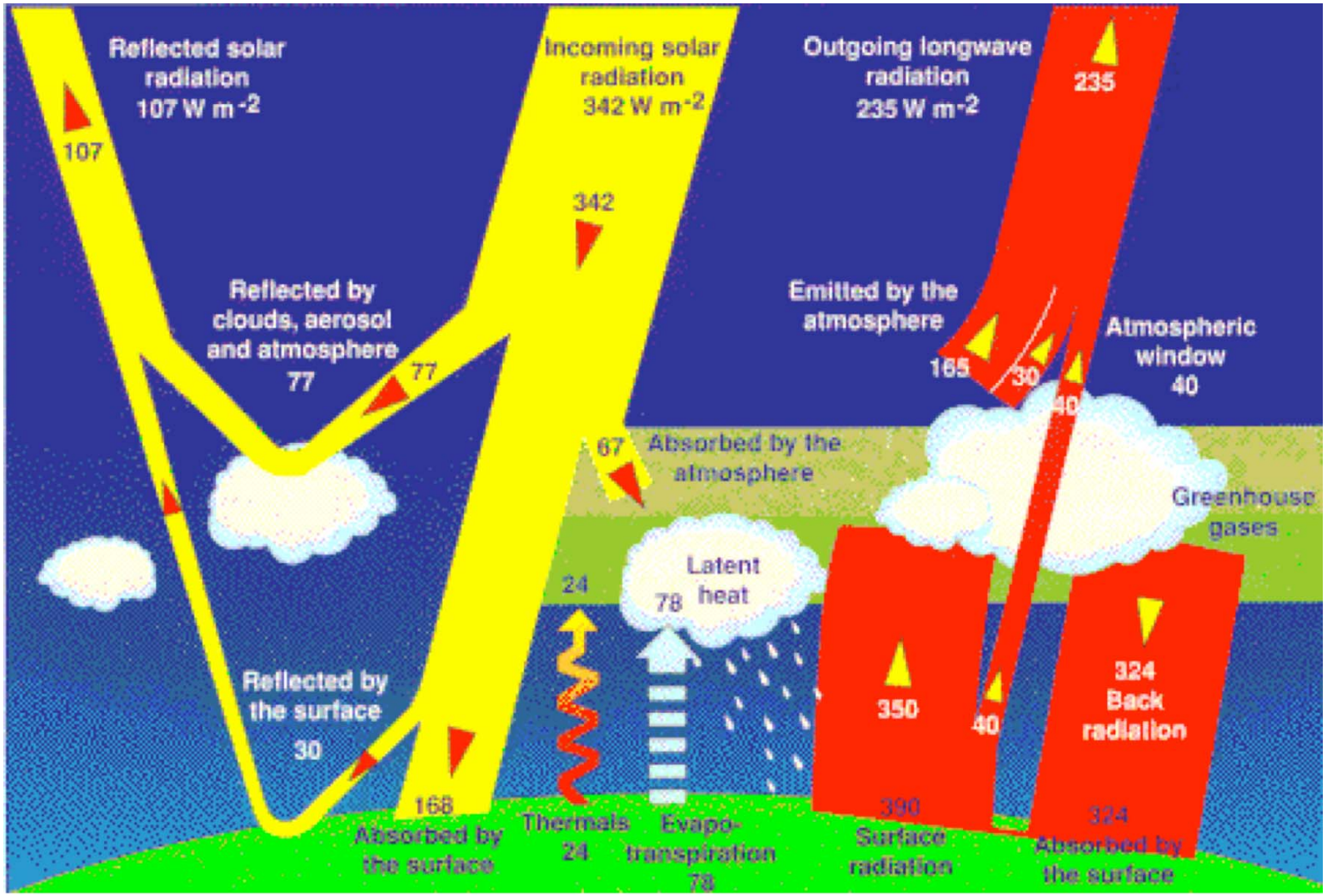
- Science Need for Net Flux Measurements
- Overview of Net Flux Measurements
- Historical Background
- The INFLAME Concept
- Current Status

Overview of Earth's Radiation Budget



Kiehl and Trenberth, 1997

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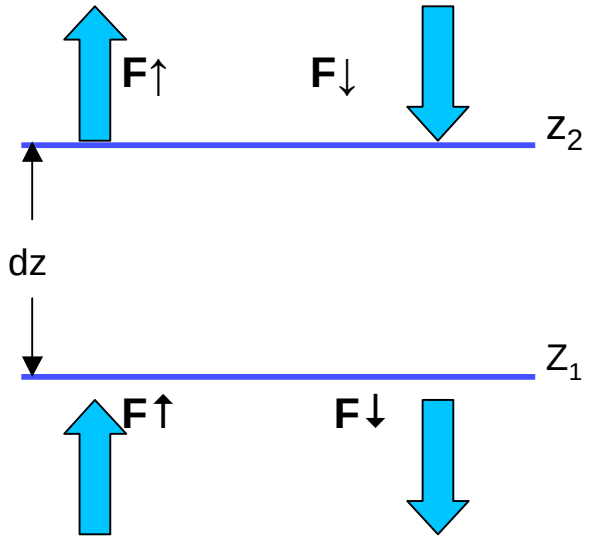
Atmospheric Heating and Cooling Rates

$$F\uparrow(z) = 2\pi \int_0^1 I(z)\,\mu\,d\mu$$

$$F\downarrow(z) = 2\pi \int_{-1}^0 I(z)\,\mu\,d\mu$$

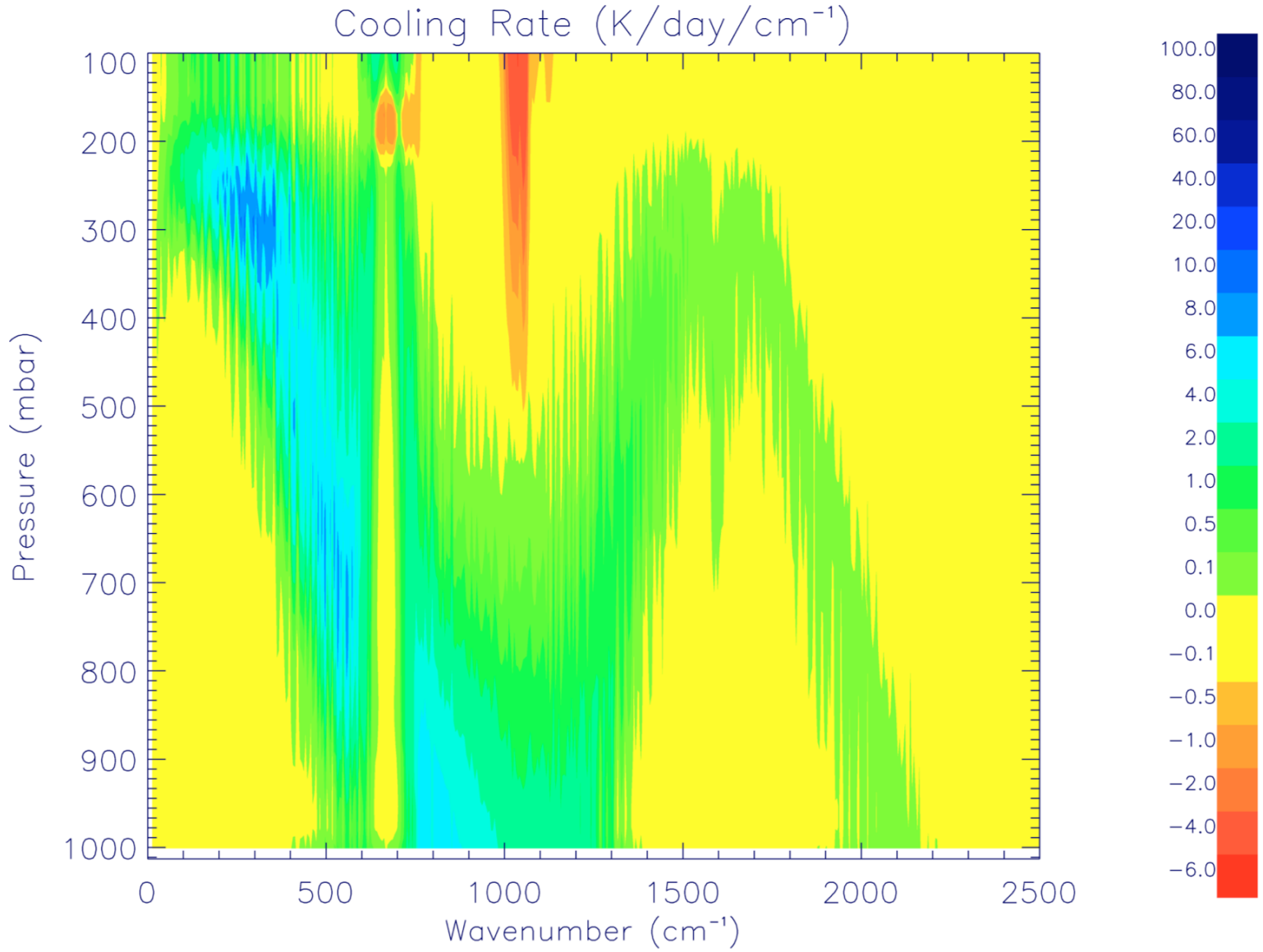
$$F_{net}(z) = F\uparrow(z) - F\downarrow(z)$$

$$\frac{\partial T}{\partial t} = \frac{1}{\rho\, C_p} \frac{\partial F_{net}(z)}{\partial z}$$



Require an instrument capable of *directly* measuring the net flux

Infrared Cooling Rate



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INFLAME addresses a fundamental aspect of atmospheric radiation:

Measurement of the rates of heating & cooling of the atmosphere by visible and infrared radiation

Every atmospheric model has essentially 3 equations

- **Momentum: (F = ma)**
- **Continuity: (Conservation of mass)**
- **Energy: (First Law of Thermodynamics)**

Energy equation requires knowledge of rate at which atmosphere heats and cools

- **Radiation**
- **Latent process (water condensation/evaporation)**
- **Conduction, etc.**

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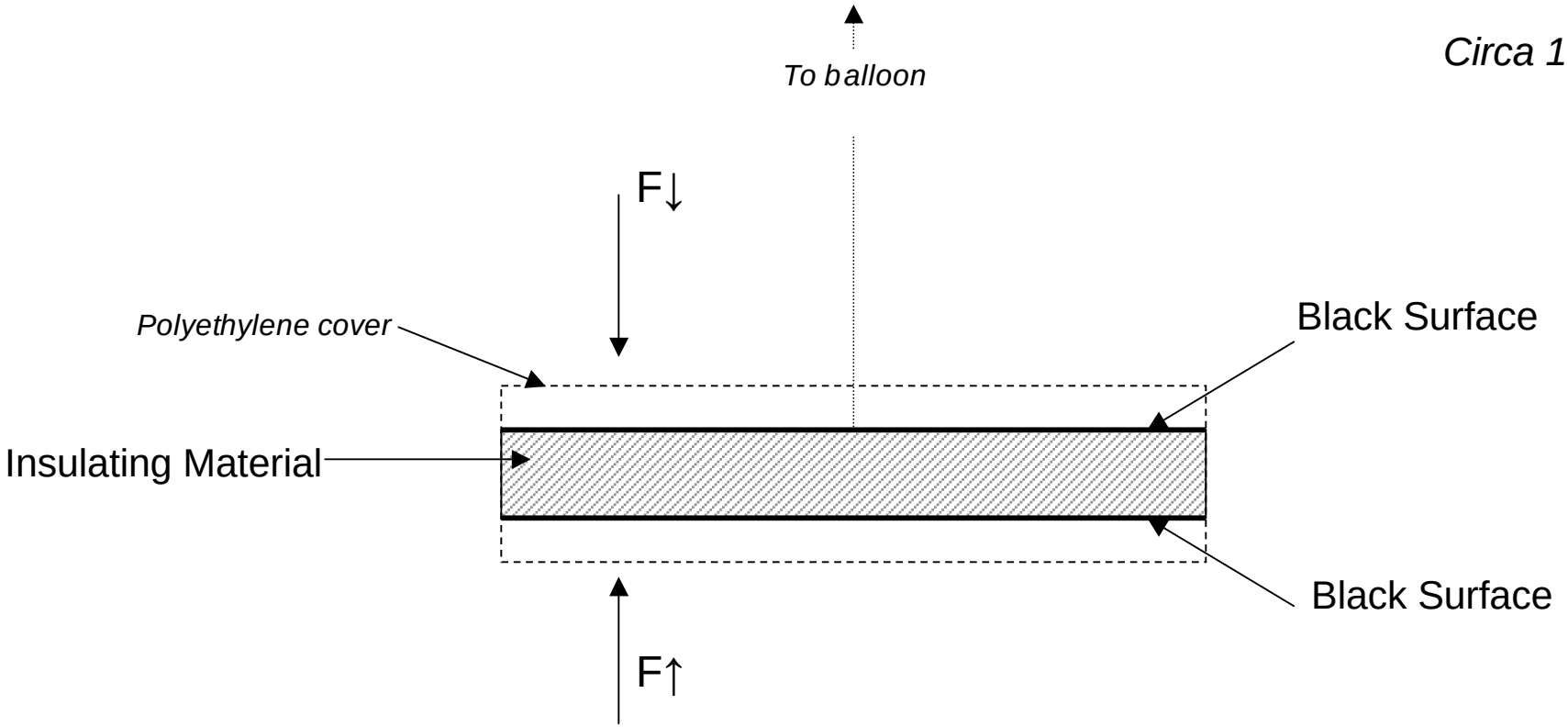
The Suomi “Economical Net Flux Radiometer”

Circa 1960



$$\frac{\partial T}{\partial t} = f(T_b, T_t, T_a, r, a, d, k)$$

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Contemporary Approaches to Net Flux Measurement

- Involve radiometric measurements from aircraft
  - Measure upwelling and downwelling streams of radiation
  - Sometimes with two separate instruments
  - Difference the two measurements to obtain net

- Drawbacks
  - Requires high absolute calibration
    - Few percent uncertainty in calibration results means error in net flux is larger than net flux itself
  - Often *radiance* and not *flux* measured
    - Requires scene-dependent and wavelength-dependent radiance to flux conversion

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The INFLAME Concept and Vision

"An Economical Net Flux Interferometer"

- Use low-resolution Fourier transform spectrometer to measure *directly* the difference between upwelling and downwelling radiation
- Anticipate that systematic errors will be reduced by differencing signals optically rather than by subtracting signals as measured by independent detector systems
- Winston cones at inputs gather radiation over 2π steradian, cosine weighted, as needed for flux and net flux measurements

INFLAME will directly measure the net flux

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The INFLAME Concept and Vision

"An Economical Net Flux Interferometer"

- Develop two separate FTS systems, one for infrared radiation, one for visible radiation
- Mount on wing tip pods of a UAV
- Cycle up and down in altitude recording vertical profile of net flux
- Derivative of net flux w/r/t altitude is the atmospheric heating rate due to radiation
- Small enough, and low cost, to enable several to be deployed at once to address issues of cloud noise, inhomogeneous nature of aerosol layers, etc.

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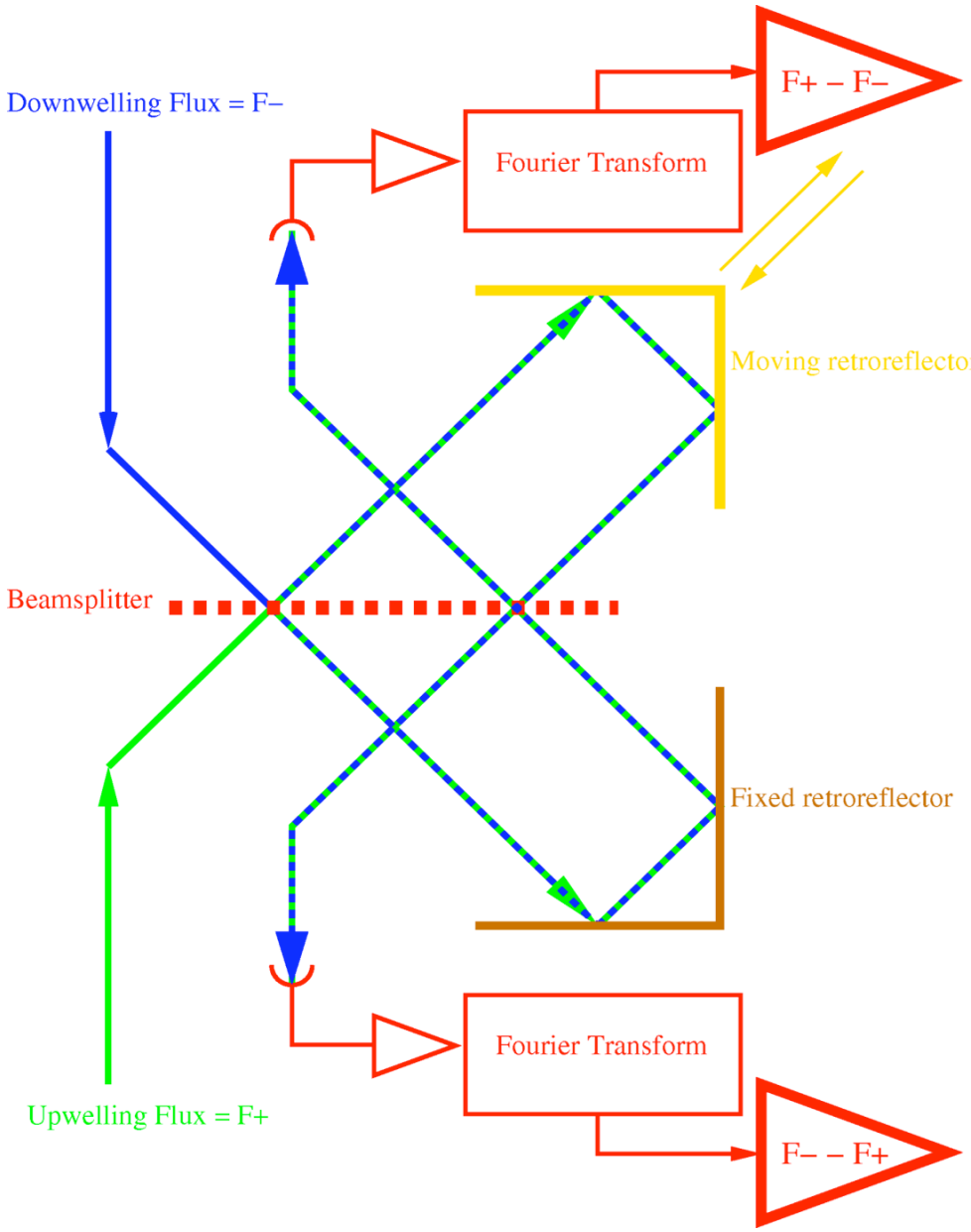
Downwelling Flux = F–
Fourier Transform
F+ – F–
Moving retroreflector
Beamsplitter
Fixed retroreflector
Fourier Transform
Upwelling Flux = F+
F– – F+

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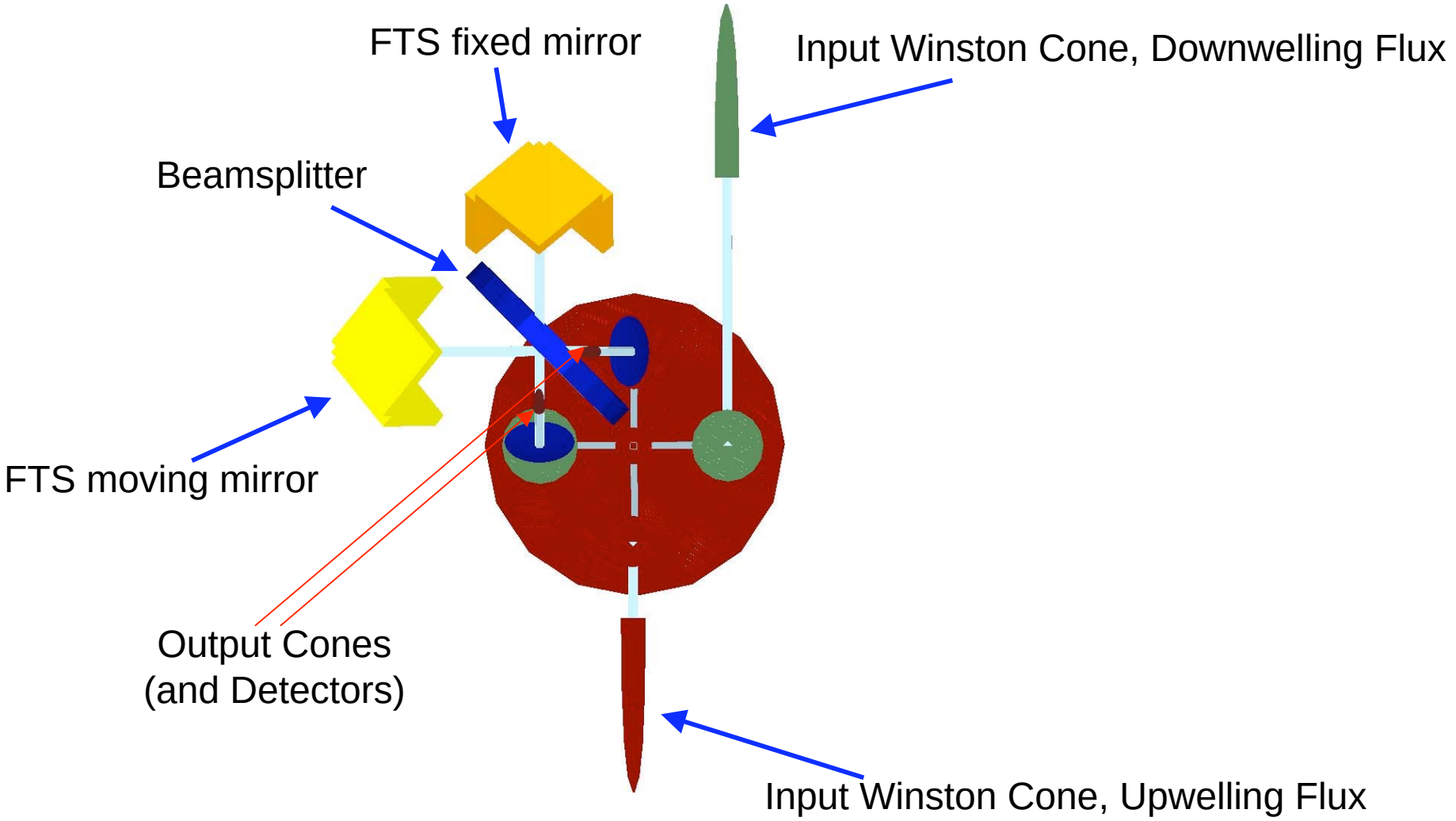
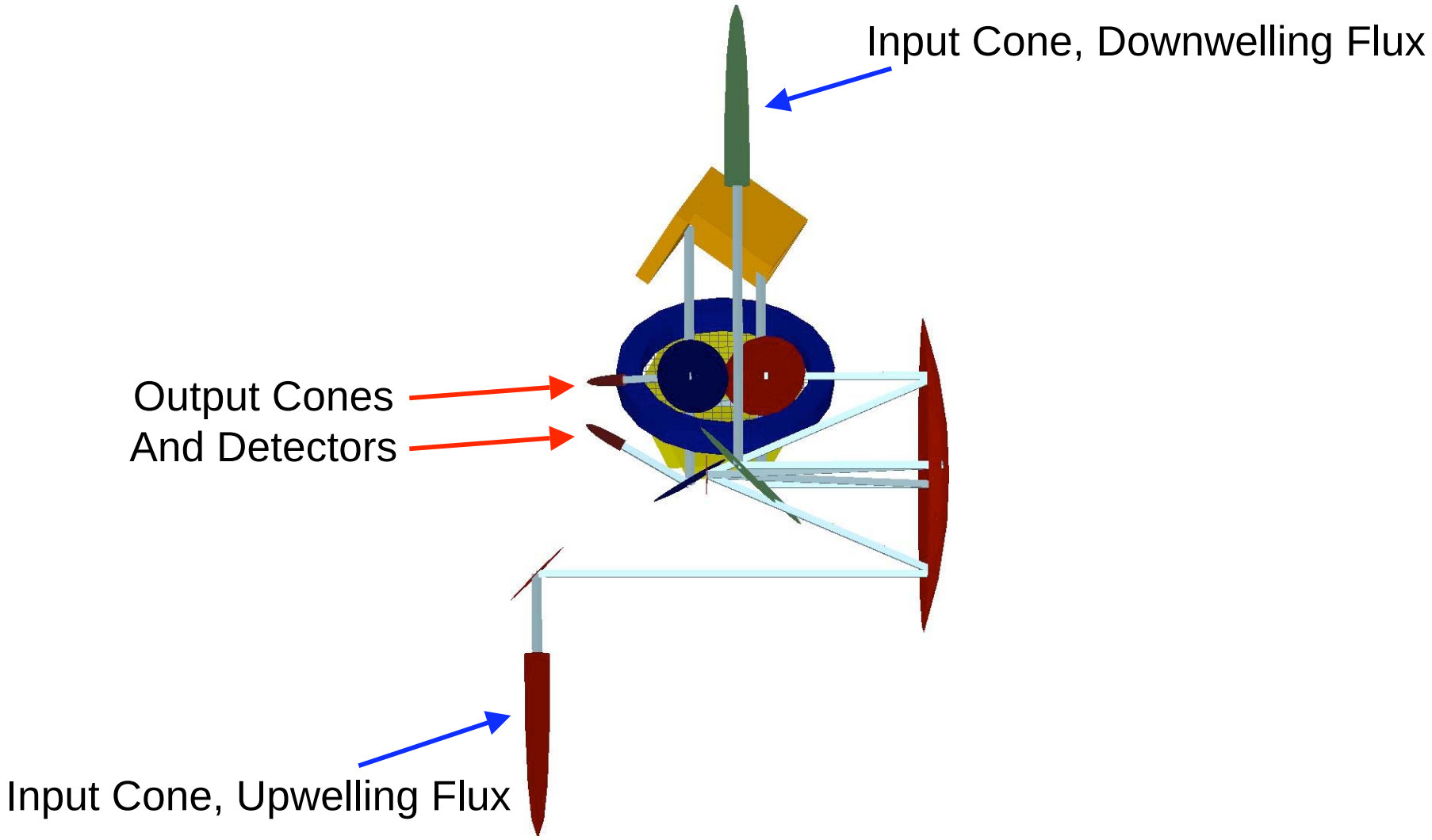
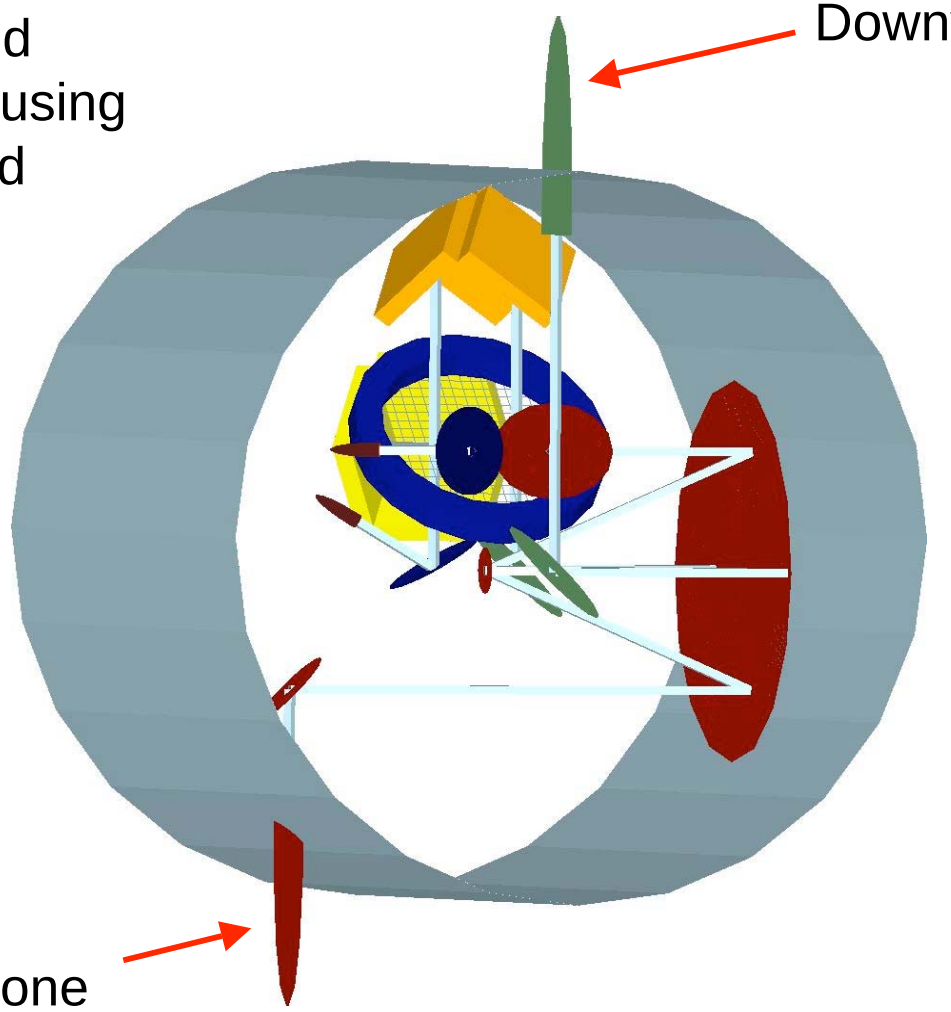

FTS fixed mirror
Input Winston Cone, Downwelling Flux
Beamsplitter
FTS moving mirror
Output Cones
(and Detectors)
Input Winston Cone, Upwelling Flux

INFLAME – Reverse View



INFLAME – Nominal Concept in Housing

Cones will extend slightly out of housing on UAV wing pod



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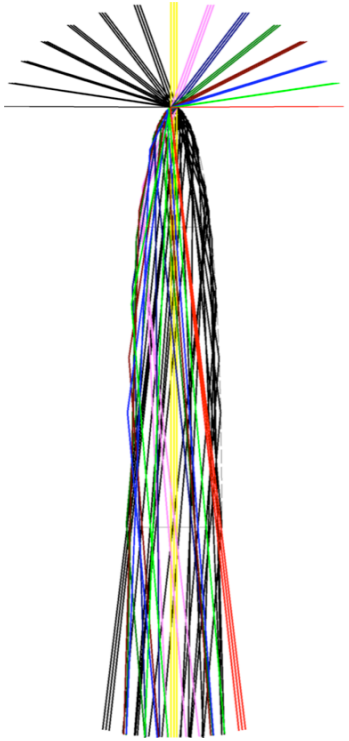
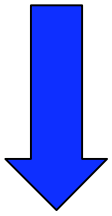
Input Radiation from Atmosphere
2π Steradian



Input to FTS



Winston cone “used In reverse” collimates hemisphere of atmospheric radiation for input to FTS

To measure ***flux***, Winston cone must provide cosine weighting to each pencil of radiation

$$F\downarrow(z) \;=\; 2\pi\int_{-1}^{0} I(z)\,\mu\,d\mu$$

$$\mu = \cos\Theta$$

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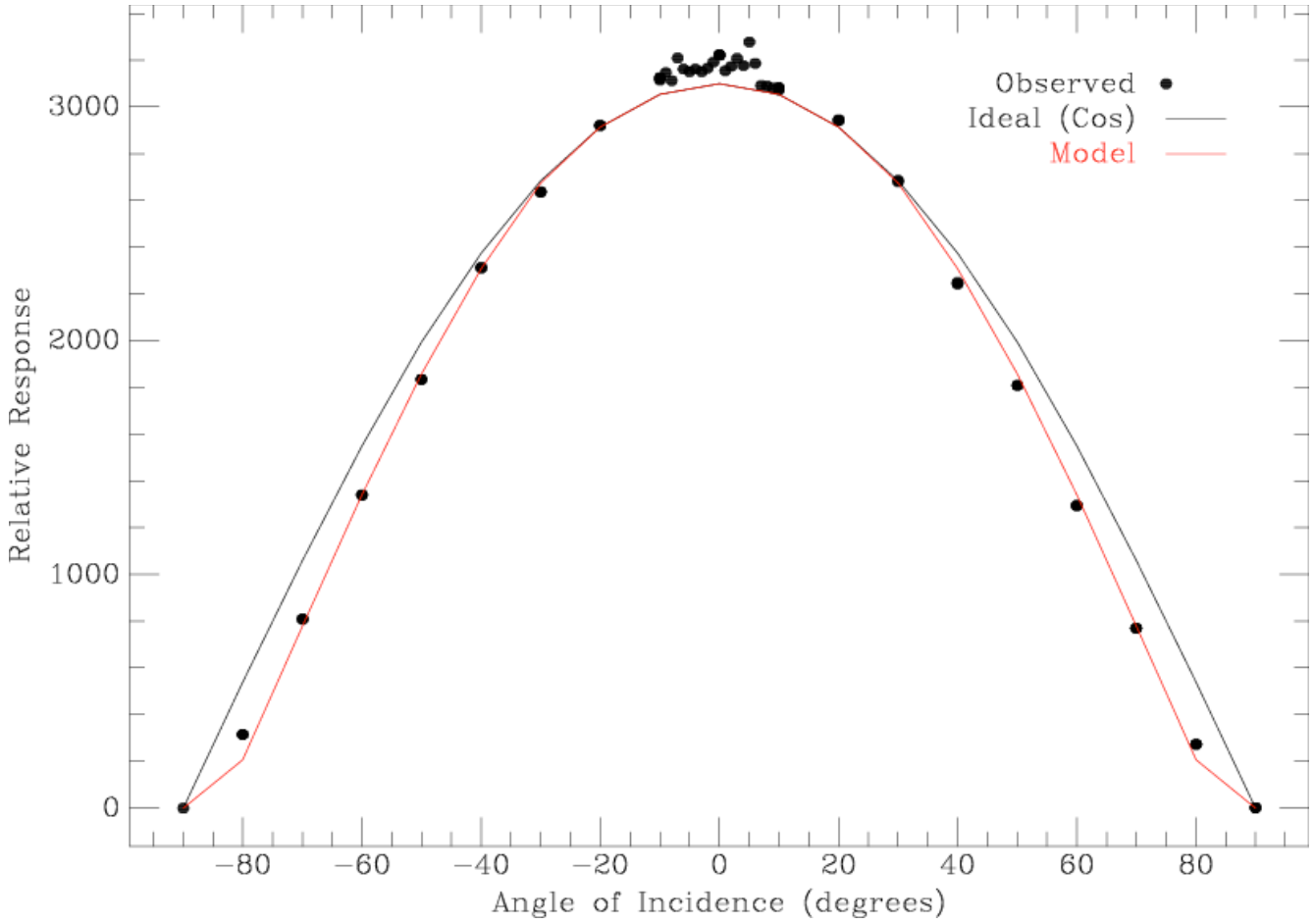
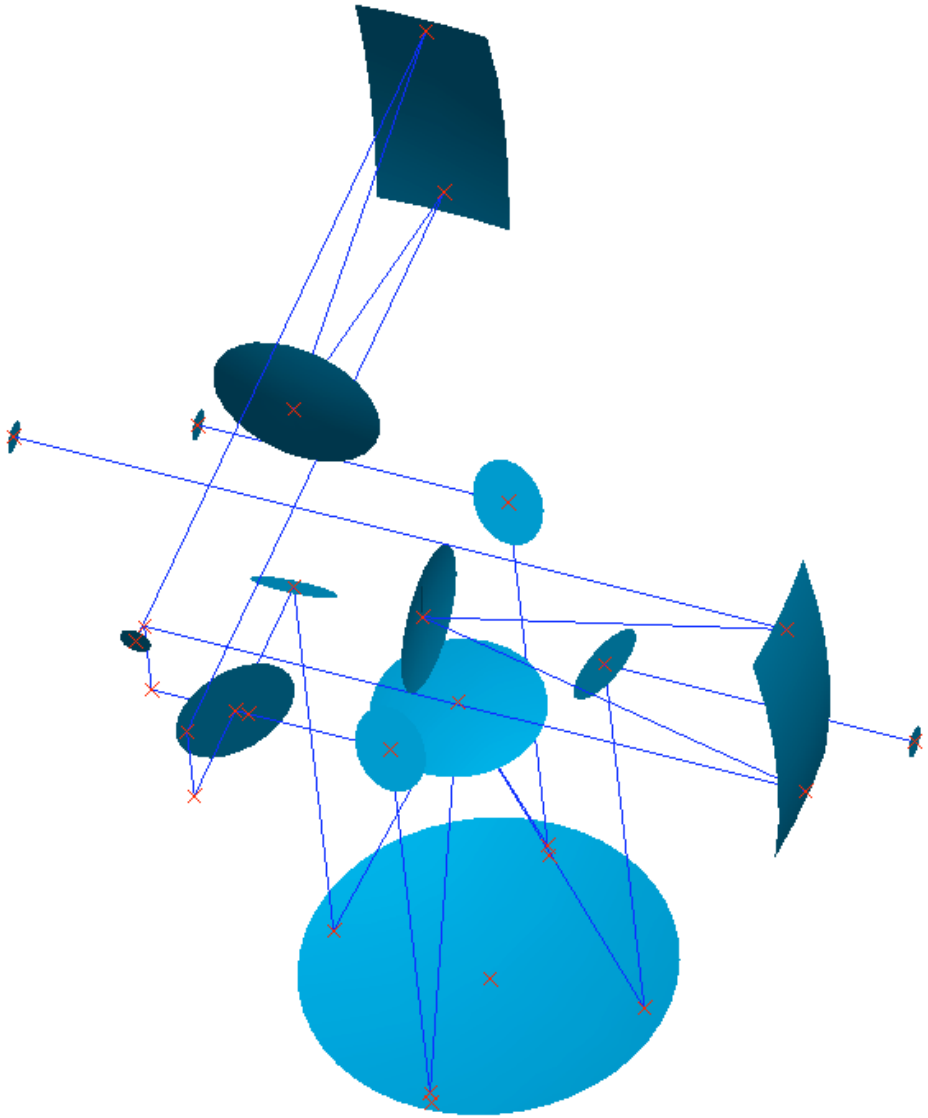
Winston Cone Angular Response



INFLAME RAY TRACE
(6/2/2006 DATA)



INFLAME – Vital Statistics

- Mass – 15 kg per sensor
  - Includes mass of vacuum housing
- Power
  - Maximum (peak) 250 W – keeps heaters running
- Data Rate
  - 14 Kbps
- Optical Path Difference
  - 7.5 mm
  - Allows mirror translation with accurate piezoelectric drive
- Spectral Resolution
  - 67 cm^{-1} – may be able to increase to ~ 20 cm^{-1}
- Volume
  - Approximately 1 ft^3

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- **Status**
  - Electronics design nearly complete
  - Optical design 100% complete – tolerance analysis underway
  - Site visit (4/2006) to General Atomics for Predator B
  - Corner cube translation stage selected
  - Moving to PDR / Authority to Proceed to Year 2 / October 2006

- **Acknowledgements**

  - NASA ESTO and IIP Program
  - NASA Science Mission Directorate
  - NASA Langley Research Center

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- **Summary**
  - **INFLAME addresses a fundamental (and difficult) problem in atmospheric radiation – the measurement of heating and cooling rates within the atmosphere**
  - **Use FTS to directly measure the net flux via optically "chopping" the two beams and determining their difference**
  - **Many of systematic uncertainties cancel out, reducing requirements on absolute accuracies**
  - **INFLAME will be UAV-borne, ideal for studying effects of pollution and aerosols on radiation, providing fundamental verification of radiative transfer codes for climate models**

General Atomics Predator-B UAV
Under Consideration for INFLAME

Backups

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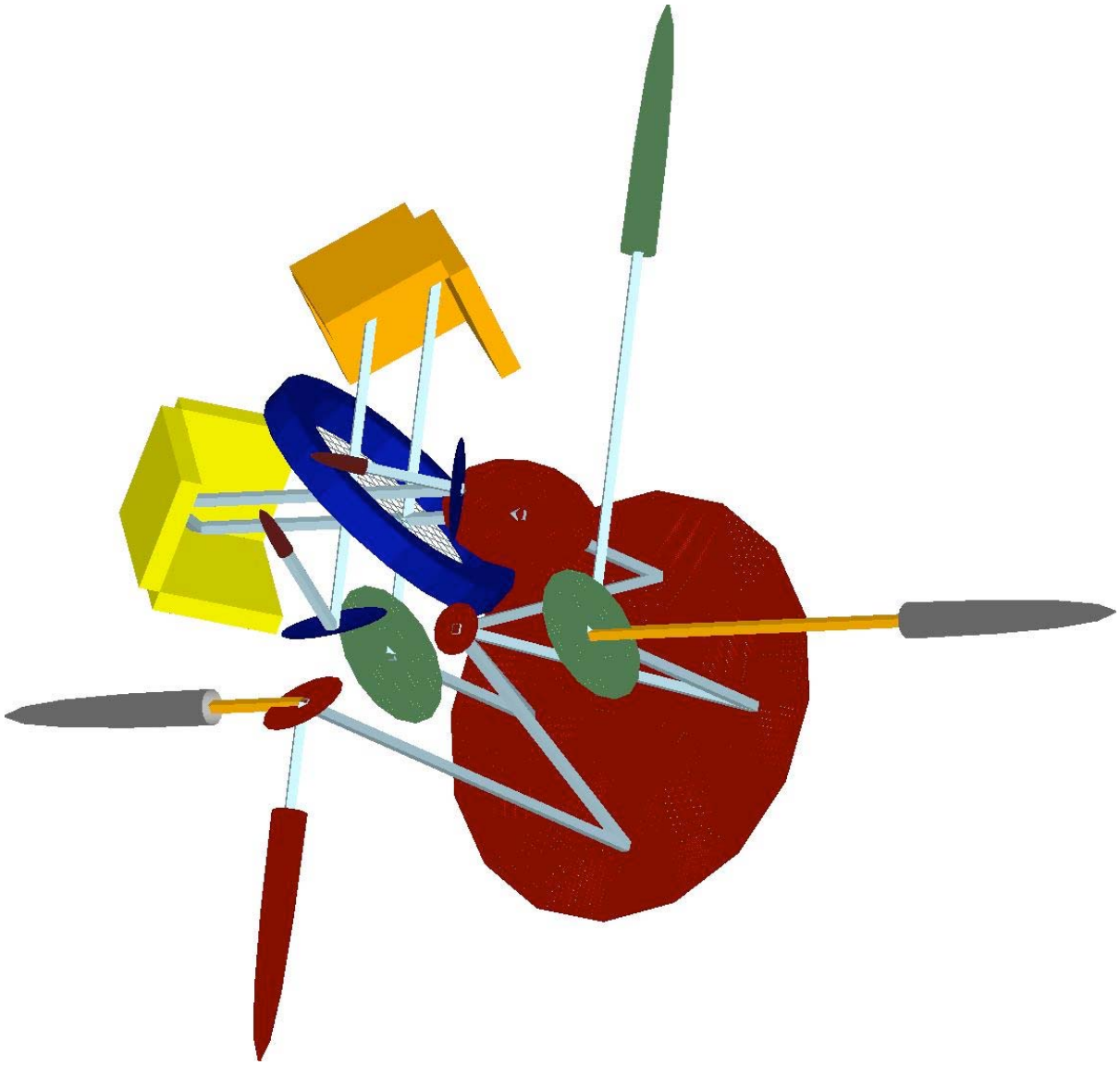
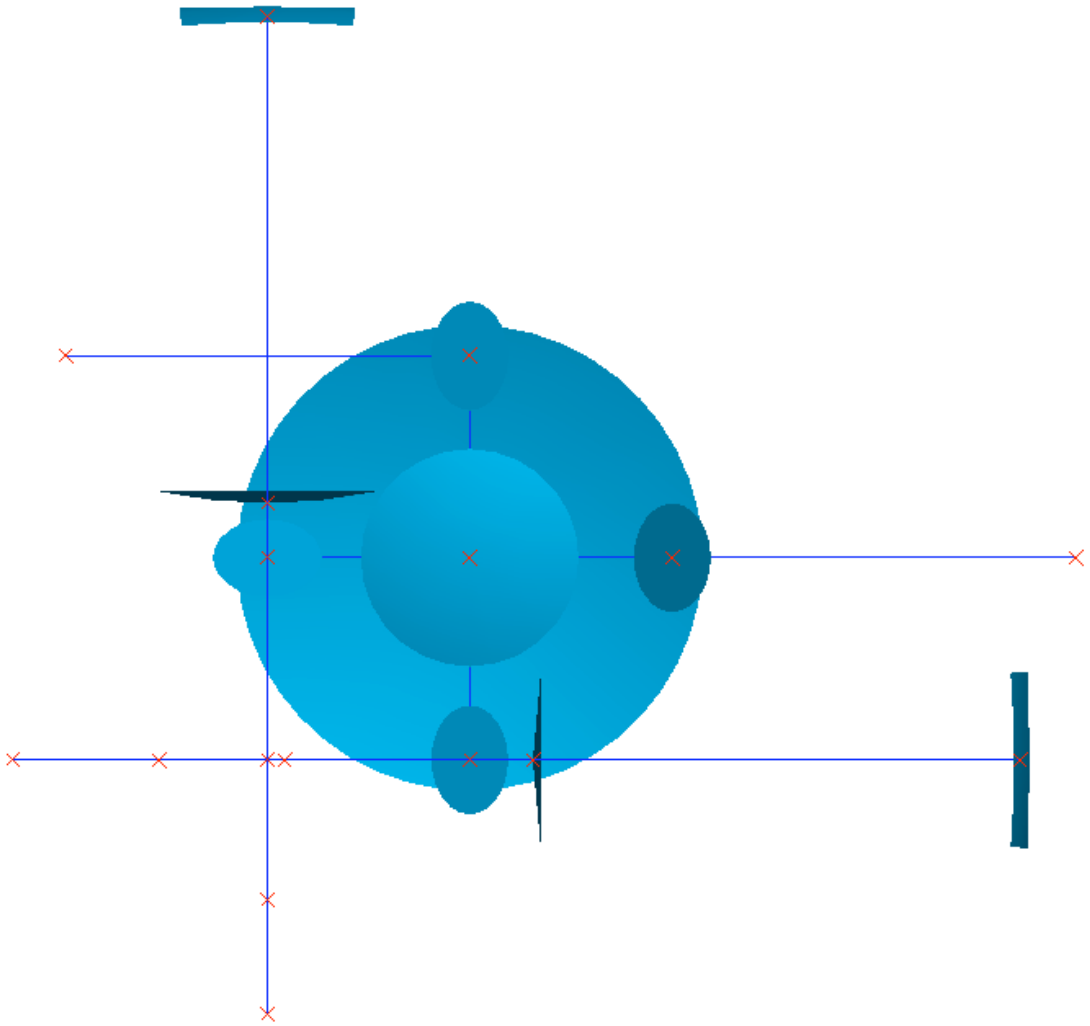
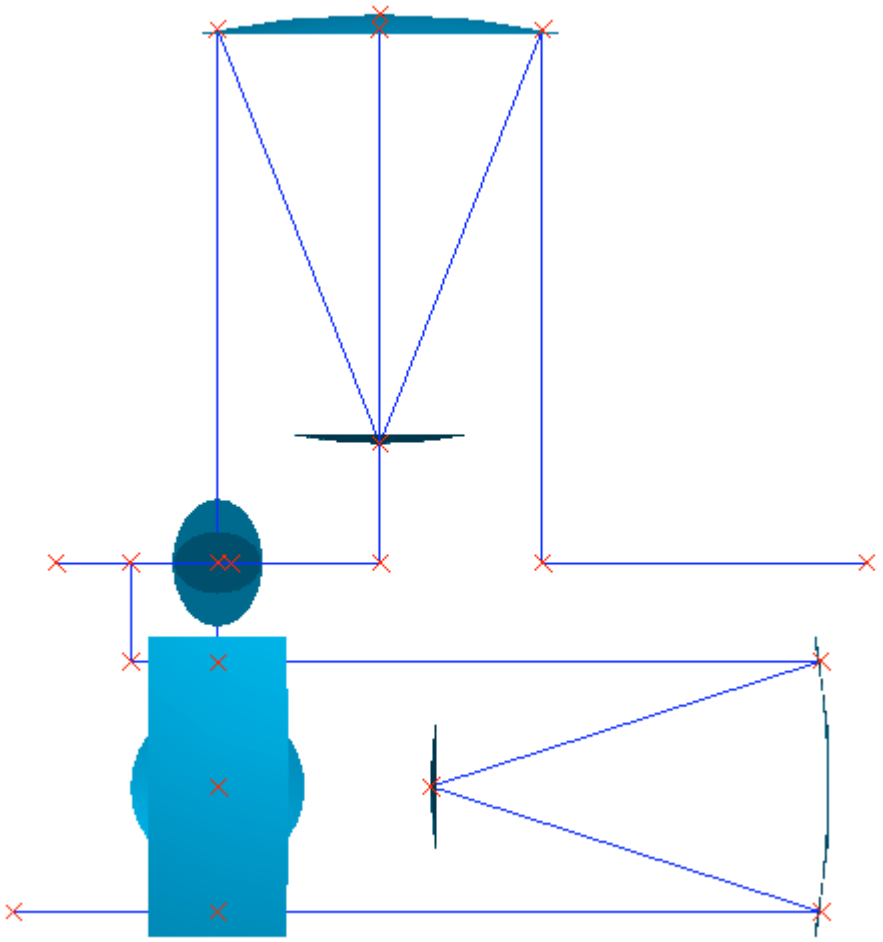


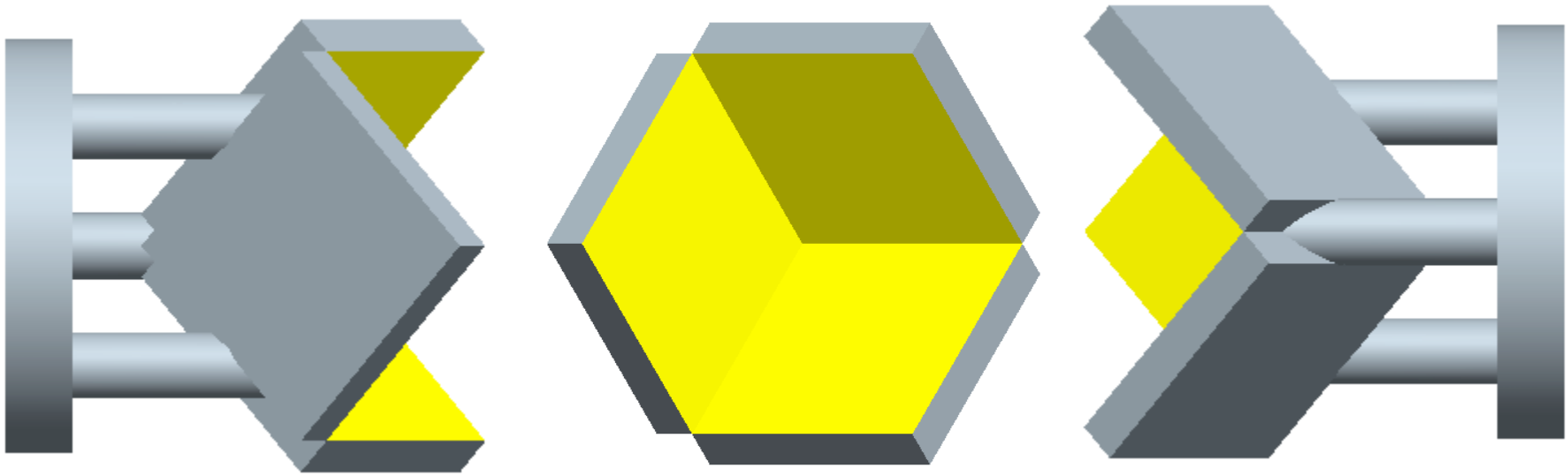
INFLAME RAY TRACE
COMPOSITE UP/DOWN SWL (6/2/2006 DATA)



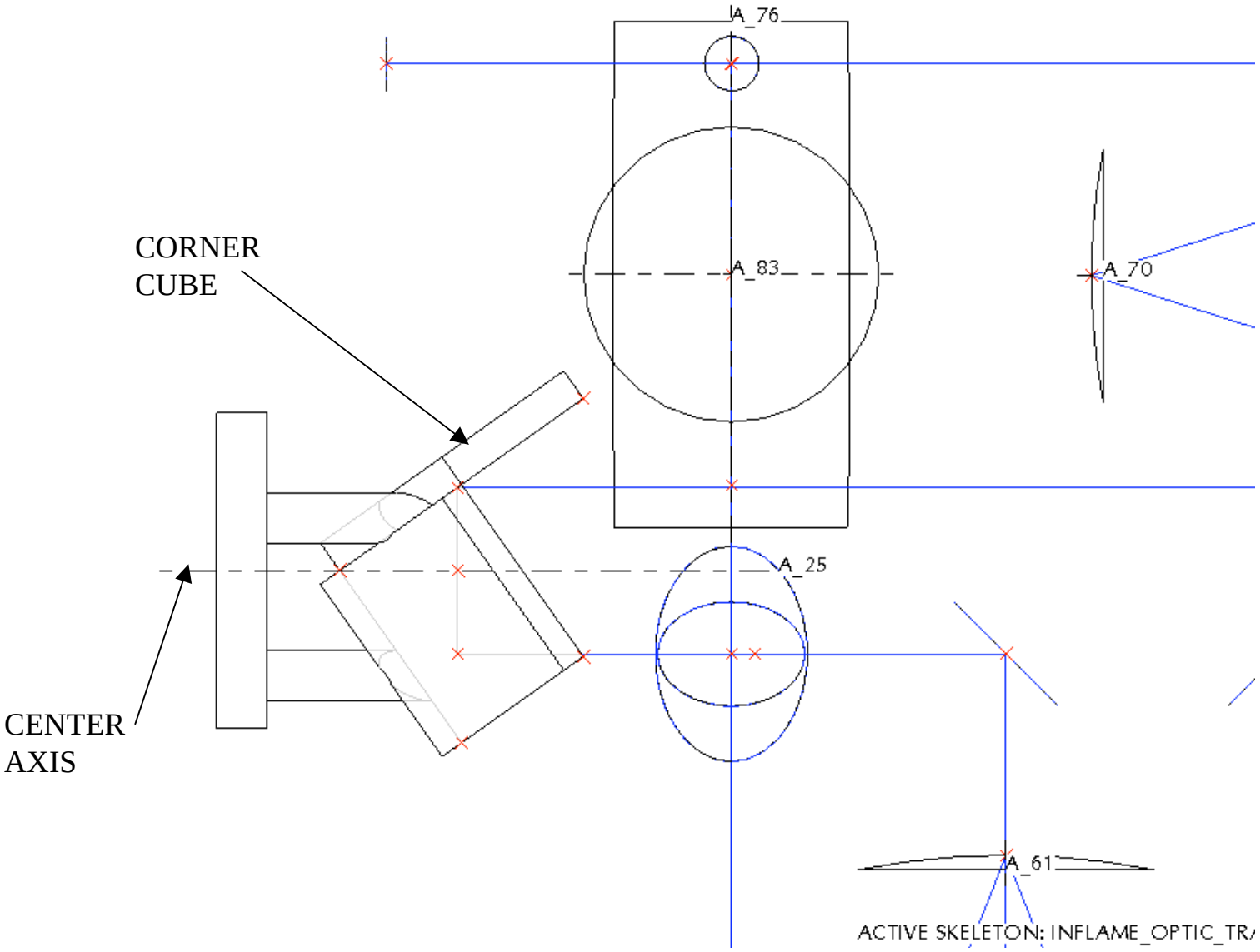
INFLAME RAY TRACE
COMPOSITE SIDE VIEW (6/2/2006 DATA)



CORNER CUBE
VIEWS



CORNER CUBE FOCAL POINT



PIEZO-NANO STAGE
2.5 KG MASS